SPRING 2003 ICHTHYOPLANKTON RECRUITMENT TO THE DELTA NURSERY AREAS OF NUECES BAY, TEXAS

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EXECUTIVE SUMMARY

The objective of this study is to quantify the spring season recruitment of larval fishes to the nursery areas of Nueces Bay, Texas, and compare the distribution of fish larvae within the bay in relation to the discharge location of the major riverine input, the Nueces River. Currently, the river discharges into the bay at a location away from the Nueces Delta region - the marsh habitat complex that provides an important nursery area function for many finfish and shellfish species.

Numerous commercially and recreationally important finfish species are considered estuarine-dependent in their early-life-history stages, and as such, they must find suitable estuarine nursery habitats. For species that spawn in areas distant from these nursery areas, planktonic larvae face a wide variety of biotic and abiotic factors that can greatly influence their dispersal into estuaries. These factors can greatly influence larval survival and recruitment, and successful recruitment events can ultimately affect adult populations.

One additional water circulation vector potentially affecting the distribution of larval fish in Nueces Bay was the AEP-Central Power and Light Nueces Bay Power Plant. This structure draws water from the Corpus Christi Ship Channel inner harbor to cool the generators and discharges it into the upper portions of the bay at a rate of about 500 cubic feet per second.

Larval fish sampling was conducted biweekly during spring 2002 (7 Feb to 3 Jun) at four fixed locations along a transect from the bay mouth, through the river discharge zone and up to the front of the delta edge. Two stations were located in the eastern portions of the bay - one at the connection with Corpus Christi Bay and another near the outfall of the AEP-CP&L facility. The two other stations were located in the western half of the bay (i.e., the back bay) - one across from the river discharge location across from White's Point, and the other at the face of the delta. At each Station, triplicate ichthyoplankton collections were taken during daylight hours, and collections were standardized to reflect larval fish densities (numbers per 100 m^3 water filtered). Environmental water quality parameters (temperature, salinity, dissolved oxygen, pH, and turbidity) were recorded prior to ichthyoplankton sampling.

Fish larvae were sorted and identified to the lowest possible taxon, enumerated, and measured to the nearest 0.1 mm. Community structure of the ichthyoplankton among the Stations was determined by ordination techniques, including hierarchical agglomerative cluster analysis and non-metric multidimensional scaling. For each technique, the Bray-Curtis coefficient was employed as the similarity measure for analysis. Length frequencies of the most abundant ichthyoplankton were tested for differences among Stations with the Pearson's Chi-square test statistic. Environmental abiotic data was tested for differences among Stations with a one-way analysis of variance.

Consistent patterns for each environmental variable were seen within Nueces Bay during the spring of 2002. Temperature, salinity, and dissolved oxygen were higher in the eastern parts of the bay (areas closest to the connection with Corpus Christi Bay), whereas lowest mean values were found in the western parts of the bay (back bay Stations nearest to the delta region). Only salinity departed from this pattern, with the lowest salinity values found directly across from the river discharge zone. Turbidity measurements were opposite of the other environmental parameters, with highest mean values at the river discharge zone, and lowest values in the eastern portions of the bay.

The nine sampling trips during the spring season of 2002 resulted in the collection of 54,527 larval and juvenile fishes representing 27 species from 16 families. Numerically, three families accounted for 98.9% of the total (Engraulidae 62.5%, Gobiidae 26.3%, and Clupeidae 10.1%). Overall ichthyoplankton abundance was unimodal, with the greatest proportion of individuals collected from mid-April to mid-May.

Ordination of the ichthyoplankton community resulted in five larval fish assemblages, separating groups of Stations both temporally and spatially. Group A included samples taken in the early spring in the eastern parts of the bay and consisted mainly of pipefish (*Syngnathus scovelli*) and pinfish (*Lagodon rhomboides*). Low numbers of clingfish (*Gobiesox strumosus*) and Blenniidae larvae also characterized Group A. Group B also included collections from the early spring but consisted of larger sized individuals taken from the back bay stations, including juvenile-sized menhaden (*Brevoortia patronus*) and bay anchovy (*Anchoa mitchilli*). Larval-sized individuals from Group B included pinfish, spot (*Leiostomus xanthurus*), and Atlantic croaker (*Micropogonias undulatus*).

The greatest densities and highest degree of community diversity was found in Group C, and this group included samples taken from all stations during the main recruitment period of mid-April to May. Within the Group C community cluster, spatial separation of bay habitats is suggested by the distribution of the engraulids, with highest densities of larval-sized individuals found in the eastern portions of the bay and highest densities of juvenile-sized individuals found in the western, back bay locations. Larval gobies (Gobiidae), blennies (Blenniidae), and clingfish were collected from all stations along the bay-wide transect, but highest densities of each taxa were typically found closer to the back bay stations. Two species in Group C that were found predominantly in the eastern part of the bay were both late spring/early summer spawning sciaenids (silver perch *Bairdiella chrysoura* and spotted seatrout *Cynoscion nebulosus*).

Group D consisted of end of the season samples taken from the mid to back bay locations and were comprised of low numbers of juvenile bay anchovies and pipefish. Larval gobies, anchovies, and blennies typified this end of the season collection. The Group E community was early season samples consisting of larval gobies, clingfish, and blennies collected from the mid to front bay locations.

The most abundant ichthyoplankton (Engraulidae, Gobiidae, and Clupeidae) were tested for differences in length frequencies among the stations in order to assess any partitioning of habitats by the recruiting species. Engraulids were bimodal at each station, with two main cohorts (4-8 mm and 16-22 mm) observed. The larger size class was presumed to be a fall/winter cohort and the smaller individuals were presumed to be spring spawned. Engraulids showed a partitioning of habitats, with the greatest proportion of juvenile-size class individuals being found in the back-bay stations. Larval anchovies were much more prevalent in the eastern part of the study area, closest to the connection with Corpus Christi Bay. Gobiidae larvae were unimodal (3-5 mm) and found at much higher abundance in the back bay locations. Clupeids were primarily collected as juveniles (20-24 mm) and were also found in higher abundances in the back bay locations.

Larval abundances of many of the species found during the spring 2002 study (particularly those that spawn outside the bay and in the Gulf) indicate that back bay locations near the Nueces Delta region may be preferentially sought by the early life history stages. Though a strong salinity gradient was not always present in the bay, some taxa appear to be recruiting to this highly productive area of the bay.

I. INTRODUCTION

The importance of estuaries as nursery grounds for a variety of marine organisms has been well documented (Knox 1986; Heck et al. 1989; Livingston 1997; Tolan et al. 1997; Le Pape et al. 2003). Experimental investigations into some of the mechanisms thought to make estuaries a preferred habitat include increased food availability, refuge from predation, increased living space, and habitat richness (Heck and Thoman 1981; Leber 1985; Jordan et al. 1996; Adams et al. 2004). High rates of primary production within estuaries are generally associated with nutrient loadings from freshwater input (Skreslet 1986), and overall high rates of productivity are maintained by a complex of emergent vegetation, benthic algae and phytoplankton which efficiently utilizes the inputted nutrients within the estuary (Schelske and Odum 1961).

Estuaries of the Gulf of Mexico are typically shallow, turbid, and well mixed with circulation predominantly wind-driven and characterized by mixed tides and small tidal amplitude (Lyczkowski-Shultz et al. 1990; Raynie and Shaw 1994). The Nueces River, the major riverine input into Nueces-Corpus Christi Bay, Texas, currently discharges into the bay at a location isolated from the historic river delta. The current river discharge point is isolated from the emergent marsh, submerged aquatic vegetation and intertidal flats that are thought to provide the primary nursery habitat function. Despite this “hydrologic-disconnect,” the Nueces Delta is considered an important nursery area for many commercially important finfish and shellfish (Henley and Rauschuber 1981; Tolan and Newstead 2003).

Freshwater inflow into the Nueces Estuary is governed by the operation of a double-reservoir system on the Nueces, Frio, and Atascosa Rivers. This departure from the traditional riverine-estuarine structure may be affecting the habitat value of the delta area as a nursery for larval fishes and shellfish. The purpose of this study is to quantify larval recruitment into Nueces Bay along a transect from the mouth of the bay, through the river discharge zone, and into the estuarine nursery area of the Nueces Delta.

Purpose and Scope

The importance of freshwater inflows to the maintenance of estuarine function has been demonstrated by numerous studies (Grange et al. 2000: see Estevez 2002 for a review of methodologies; Montagna et al. 2002). Though interannual variability in flows and extended periods of floods or drought are natural features of estuaries, the addition of an anthropogenic trajectory to these other sources (in the form of freshwater diversion, reservoir operations, etc.) forces systems into artificial cycles, and consistent reduced inflow conditions can lead to degradation and loss of important nursery habitat (Powell and Matsumoto 1994, Pulich et al. 2002). The recommended freshwater inflow regime for the Nueces Estuary, consisting of a series of monthly inflow targets as determined by Pulich et al. (2002), shows that inflows would be most beneficial if delivered in proximity to the delta region in one or two pulsed events in the spring (the time of historical maximum flows), or, secondarily (in the case of persistent low flows in spring and summer), in the fall. This is a departure from averaging flows throughout each season, as the estuarine biota appears to respond most favorably to more naturalized hydrologic events within this estuary. As a result of the adaptive-management practices of realizing the maximum benefit for the volume of freshwater passed through the reservoir system to the bays (Bureau of Reclamation 2000), a proposal was offered to move a monthly portion of the freshwater inflows, via a pipeline, directly into the upper portion of the Nueces Delta. Components of the Recommended Monitoring Plan for Rincon Bayou, Nueces Delta (NEAC 2002) included:

- Re-open the Nueces River overflow channel,
- Make the Nueces River overflow channel and the Rincon Bayou overflow channel permanent features of the Rincon Bayou Diversion,
- Construct and operate a pipeline with the capability to deliver up to 3,000 acre-feet per month from the Calallen Pool to Upper Rincon Bayou, and
- Implement a monitoring program to facilitate an “adaptive management” program for freshwater inflows into the Nueces Estuary.

This ongoing study provides the baseline, pre-pipeline characterization of larval recruitment into the estuarine nursery areas of Nueces Delta.

The objective of this study is to determine the extent of larval recruitment to the Nueces Delta, and compare the distribution of fish larvae and shrimp post-larvae (PL) within Nueces Bay as related to discharge of the Nueces River. Specific objectives of the study are to (1) document the distribution of ichthyoplankton and shrimp PL along a transect from the mouth of the bay through the river discharge zone and into the estuarine nursery areas of the delta region; (2) to determine if the discharge of the Nueces River away from the delta region acts as a “recruitment barrier” for transport and recruitment of fish and shrimp into the Nueces Delta; and (3) collect baseline information on fish and shellfish recruitment into upper Nueces Delta in order to evaluate the effectiveness of monthly diversions of freshwater via the pipeline diversion project.

Description of the Study Area

The Nueces River watershed encompasses > 4.3 million ha within the Edwards Plateau and Gulf Coast Section of the Coastal Plains Province (HDR Engineering, Inc. 1991, see Fig. 1). The Frio River flows into the Choke Canyon Reservoir above the Nueces River, and downstream, the Atascosa River joins the Nueces River, which is impounded by the Lake Corpus Christi Reservoir. Beyond this lower reservoir, the river empties into Nueces Bay.

Nueces Bay is a secondary bay of the Corpus Christi Bay system, with a combined surface area of 518 km^2. It is a shallow, well-mixed, wind-driven bay located in a semi-arid zone. Mean precipitation of 71.9 cm yr^{-1} is exceeded by mean evaporation of 100 cm yr^{-1}. Precipitation is bimodal, with peaks in the spring and fall. Mean summer and winter air temperatures are 33.3 and 8.3˚C, respectively. Prevailing winds are southeasterly to south-southeasterly throughout most of the year, with strong northerly frontal systems occurring intermittently throughout the winter (Texas Department of Water Resources 1982). Salinity may vary from near fresh (<2‰) during heavy flood events ("freshets") to hypersaline (>45‰) during prolonged dry periods. Mean annual salinity is reported as 25‰ (HDR Engineering, Inc. 1991). Tides are primarily diurnal with an average amplitude of ~10 cm, with seasonal water levels creating a range of ~0.1 m. Tidal range is controlled primarily by the wind (Ruth 1990).

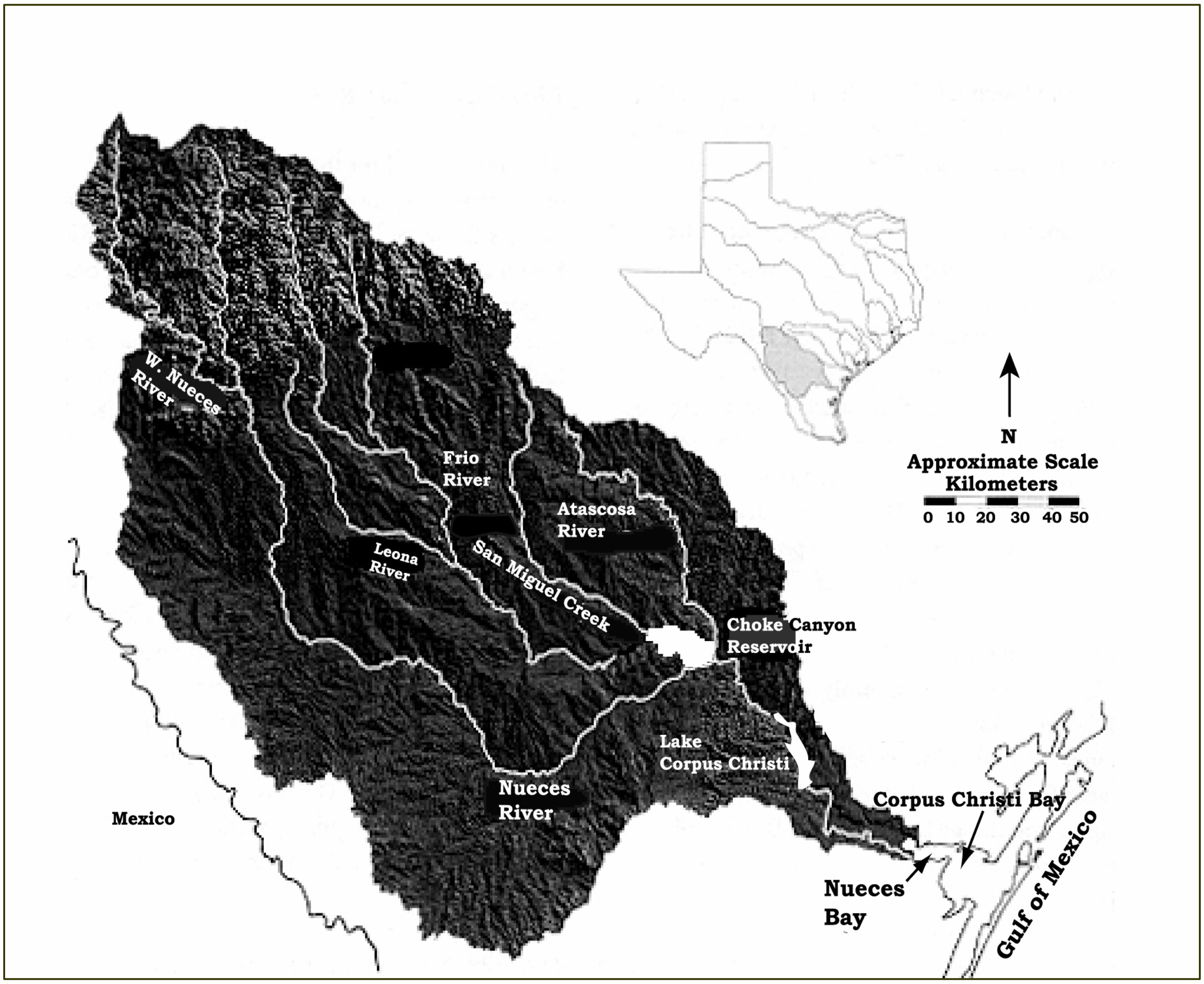

Figure 1. The Nueces River Drainage, including the two reservoirs (Modified from Bureau of Reclamation 2000).

The Nueces River currently flows along the southern edge of the Nueces Delta and empties directly into Nueces Bay (Fig. 2). The delta is an expansive area of middle- to high-marsh that is bypassed by the main river flow except during flood flows. Rincon Bayou, the historical river channel, conveys floodwaters from the river immediately south of Interstate Highway 37 (IH 37) into the delta during these events. The combined reservoir operations have resulted in a 54.9% decrease in mean annual river flow into the Nueces Estuary, and a 99.6% decrease of flow into the Nueces Delta (Bureau of Reclamation 2000). These decreased flows, coupled with high evaporation rates in the shallow delta area, resulted in the formation of a negative estuary with salinity increasing upstream (into the delta) instead of downstream (Palmer et al. 2002).

An additional (non-freshwater) inflow source into Nueces Bay was from the AEP-Central Power and Light (CPL) power plant located between the Corpus Christi Ship Channel and Nueces Bay. Water drawn from near the bottom of the Ship Channel was pumped through the power plant to cool the generators and then discharged into the southeastern portion of the bay. This input may serve as an additional recruitment vector for planktonic eggs and larvae drawn into the Inner Harbor and Ship Channel, and could also affect recruitment by altering circulation patterns in the bay (Powell et al. 1997). Cooling water discharge constituted between 14-19% of the total water input into the bay (Whitledge 1993). Although the plant ceased operations in 2003, it is still operational and has been used recently to generate electricity during periods of peak demand.

The Nueces Delta consists of approximately 5,850 ha of middle and high marsh, with 35 ha of smooth cordgrass (*Spartina alterniflora*) distributed along the fringes of tidal channels (Espey, Huston & Associates 1981). Drift algae (*Gracilaria* sp.) is the dominant submerged aquatic vegetation in the bay (Tom Wagner personal communication). Seagrasses (*Halodule beaudettii* and *Ruppia maritima*) are concentrated in small patches along the northern edge of the study area. Relict (and some extant) oyster reefs (*Crassostrea virginica*) are scattered in the western and northern portions of the bay, with a concentrated area of reefs located near White's Point, directly across from the river discharge.

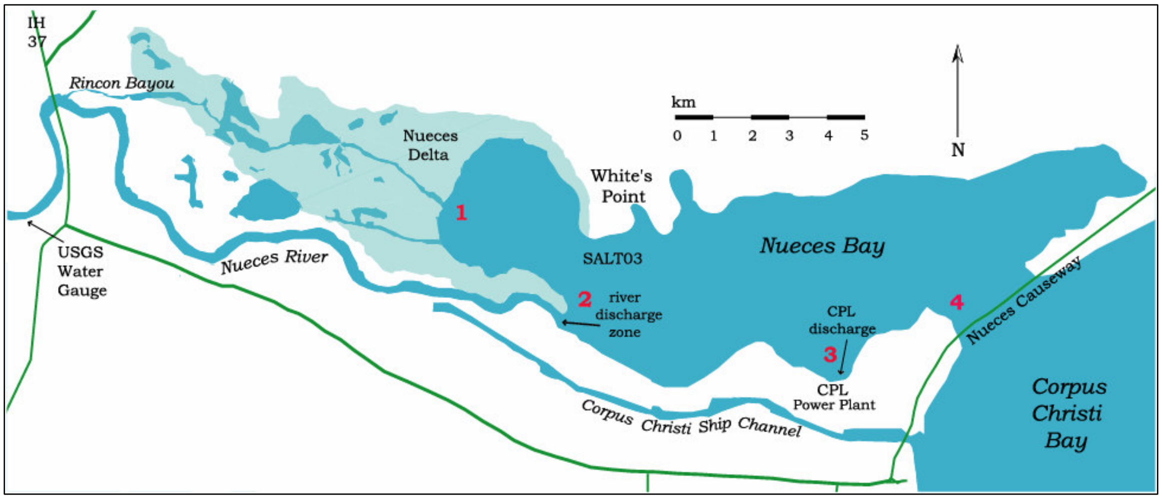

Figure 2**.** Study area with relevant surrounding features and sampling Stations for this study (Modified from United States Geological Survey 1984).

II. LITERATURE AND HISTORICAL DATA REVIEW

Recruitment can be defined as the addition of a new cohort of young individuals to a population (Sale 1990). The process of settlement or transfer of individuals from planktonic to demersal populations is a major event in the recruitment process (Sale 1990). Various biotic and abiotic factors interacting during these early life history stages can affect the dispersal and settlement. Numbers of larvae surviving dispersal and settling out of the planktonic phase may be one of the ultimate determinants in adult population sizes (Richards and Lindeman 1987). Variability in the planktonic dispersal processes has a great influence on larval supply, which may result in considerable seasonal variation in community structure (Underwood and Fairweather 1989; Roberts 1991).

Physical transport mechanisms responsible for circulation are important in the dispersal of larvae. Major influences on circulation in estuaries include tide, river flow, wind, nontidal forcing from the coastal ocean, and topographically induced circulation (Norcross and Shaw 1984). The presence of two-layered, vertically stratified current flow has been proposed as a recruitment mechanism linking offshore spawning grounds with estuarine nursery areas in some Atlantic coastal systems (Weinstein et al. 1980; Hettler et al. 1997). Upstream transport of larvae may play an important role as a mechanism linking offshore spawning grounds with estuarine nursery areas (Shaw et al.

1988). Distribution and population structure of fishes are indirectly related to the estuarine environment through food web dynamics that can ultimately be defined by changes in river flow (Livingston 1997).

Fish that utilize estuaries as nursery areas employ a range of life history strategies in order to settle into favorable habitat. A major problem encountered by these fishes is the net seaward flow of estuarine waters combined with tidal flux, which may affect transport into, or away from, estuaries (Boehlert and Mundy 1988). For those species residing in estuaries through their entire life cycle (estuarine residents), the problem of export of early life history stages is sometimes counteracted by production of large, demersal eggs and short early life history stages (Hildebrand and Schroeder 1928; Kneib 1997). Some species brood their young within a pouch (Syngnathidae) or mouth (Ariidae) (Dando 1984), or seek more protected habitats near the margins of estuaries. Estuarine-dependent species require estuarine habitat only during a particular life history stage. Many of these fishes are spawned offshore or near passes and face the problem of locating and entering estuarine areas in spite of the net seaward movement of water (Valesini et al. 1997). These fishes [including several that are commercially and recreationally important such as black drum (*Pogonias cromis*), Atlantic croaker (*Micropogonias undulates*), spot (*Leiostomus xanthurus*), spotted seatrout (*Cynoscion nebulosus*), flounder (*Paralichthys* spp.), and others] generally have an extended larval phase and experience a wide range of physical processes before potentially being delivered to an estuarine area.

The spawning of many temperate fish species is in phase with the onset of seasonal production cycles. Spring and fall phytoplankton blooms are often closely followed by increases in zooplankton abundance (Riley 1967). The “match-mismatch” hypothesis suggests that the strength of the spatial and temporal correlation between the production of zooplankton (food source) and the production of fish eggs can have significant effects on larval survival and subsequent recruitment, and thus serve as a significant source of interannual variability (Cushing 1975).

III. METHODS OF ANALYSIS

Sample Collection

Sampling was conducted approximately biweekly during the spring recruitment period in 2003. Biweekly sampling began in February and extended until early June. Hettler et al. (1997) demonstrated that estuarine-dependent fish recruitment in Beaufort Inlet, North Carolina showed an increased range of abundance estimates with increasing sampling intervals (2d, 4d, 7d, 14d, 30d between samples); however, the differences between 7d and 14d intervals were small for most target species.

Six fixed stations were sampled along a transect from the bay mouth through the river discharge zone and into the delta and river regions. Station RB51 was located along

Rincon Bayou in the delta, approximately xx km from the proposed pipeline outfall point (Fig. 2). Station NB1 was at westernmost margin of the bay, immediately outside of Rincon Bayou; Station 313 was located at the river discharge zone across from White's Point; and Station 104A was located within Nueces River, xx km upstream of the current river discharge location. Station CPL was located near the outflow of the CPL power plant; and Station NB1 was located near the Nueces Causeway, at the eastern margins of the bay where it connects to Corpus Christi Bay. Triplicate ichthyoplankton samples were collected at each station during daylight hours using a 60 cm diameter pull-net with 500 µm mesh. Except for RB51, the net was pulled in an arc in order to minimize the influence of motor wash from the boat. At RB51, the width of the channel was too narrow to pull the net as described, so it was fixed to the starboard side of the boat and used as a pushnet down the channel. A mechanical flowmeter was attached to the net allowing a calculation of the volume of water filtered, and collections are standardized to reflect fish density (fish 100 m^{-3}). Collections were initially preserved in 10% seawater formalin. After 48 h, all collections were transferred to 95% ethanol for final storage and preservation.

In the laboratory, all fish larvae and shrimp PL were sorted from whole collections, enumerated and measured to the nearest 0.1 mm with an ocular micrometer. Lengths recorded are notochord length for pre-flexion larvae, and standard length (SL) for flexion and post-flexion larvae and juveniles. Shrimp lengths are total lengths, straight-line distance from rostrum to telson. For samples containing a large number of individuals of a particular taxa, a Folsom Plankton Splitter was used to divide the whole sample in half, and this process was repeated until a reasonable number of individuals was present in the subsample. A whole count was then extrapolated from the fraction for that species, and the entire sample was searched for all other species. Fifteen individuals of each species were measured for each replicate sample. If more than fifteen individuals were present, a random subsample of 15 individuals from each species was measured. Ichthyoplankton identification was facilitated by reference to published descriptions (Fritzsche 1978; Hardy, Jr. 1978;; Johnson 1978; Jones et al. 1978; Martin and Drewery 1978; Holthuis 1980; Hoese and Moore 1992; Ditty and Shaw 1994; Farooqi et al. 1995). A description and relative quantification of zooplankton abundance was also noted during sample processing.

At each station prior to ichthyoplankton collections, water quality parameters [temperature (˚C), salinity (PSU), dissolved oxygen (D.O. mg l^{-1}, and % saturation,), pH (SU)] were measured with a YSI 6650 sonde. Turbidity was measured by secchi depth (cm). Continuous water temperature and salinity data were also collected near Station 313 by a salinity monitoring station (SALT03; see Fig. 2) operated by the Conrad Blucher Institute for Surveying and Science, and those data are incorporated into the analysis.

Data on freshwater discharge volume was obtained from a USGS water level monitoring station at Calallen (USGS 08211500) and was used as an approximation of inflow into the bay (see Fig. 2).

Statistical Tests

Ordination

The PRIMER v5.0 (Plymouth Routines in Multivariate Ecological Research) software program was used for analysis of the ichthyoplankton collection. Community structure was analyzed using multivariate non-metric Multidimensional Scaling procedures (MDS), and a non-parametric randomization Analysis of Similarity (ANOSIM) procedure. Raw fish density data were $\mathrm{Log}_{(10)}(x + 1)$ transformed and similarities between each pair of samples were calculated using the Bray-Curtis similarity measure:

$$S_{jk}(i) = 100 \left\{ 1 - \frac{\Sigma_{i=1}^{p} |y_{ij} - y_{ik}|}{\Sigma_{i=1}^{p} (y_{ij} + y_{ik})} \right\} \qquad \text{Eq. 1}$$

where y_{ij} is density of the i^{th} species in the j^{th} sample, and y_{ik} is the density of the i^{th} species in the k^{th} sample. In the Bray-Curtis measure, $S = 0$ if the two stations have no species in common, and $S = 1$ if the community composition is identical, because $| y_{ij} - y_{ik} | = 0$ for all i.

Non-metric MDS seeks to compute coordinates for a set of points in a unit-less space such that the distances between the pairs of points fit as closely as possible to the measured similarity between a corresponding set of objects (SYSTAT 1992). MDS is a graphical representation of the sample patterns, built on the ranks of the similarity matrix. The data set contains two main factors, sample date and Station, so the MDS patterns were plotted twice, once using the Station name as the symbol and once using the sample date as the symbol. Second stage MDS (Clarke and Warwick 2001) is a time-series technique incorporating the Spearman Rank (ρ) correlations between the underlying similarity matrices calculated for each sample date-Station two-way layout. Second stage MDS concentrates only on whether the community pattern among the Stations is similar temporally across sample dates.

Differences among Stations were further evaluated using a one-way ANOSIM (Clarke and Warwick 2001) on the *a priori* groups of samples. The procedure constructs a test statistic (R) based on similarities of the replicates within and between Stations. This value is then tested for significant differences against a null distribution constructed from random sampling of all possible permutations of the sample labels (Clarke and Warwick 2001). Values of the R-statistic close to unity show that the compositions of the samples are very different, whereas those close to zero demonstrate that there are very similar.

The SIMPER (SIMilarity PERcentages – PRIMER v5.0) routine was used to examine the contribution of individual species (i) to the community structure seen at each Station. Values of $S_{jk}(i)$ are averaged over all pairs of samples (j,k) between fish assemblages to give the average contribution. The ratio of $\mathrm{Savg}_{(i)}$ to its standard deviation indicates how consistently a species discriminates among the assemblages. If a species is found at consistent levels (i.e., densities) across all samples at a Station, then the standard deviation of its contribution is low, and the ratio is high (Clarke and Warwick 2001). Such a species will contribute more to the intra-group similarity, and can be thought of as typifying that group.

Length-frequencies of abundant ichthyoplankton

Length-frequencies of Gobiidae, Engraulidae, and Clupeidae were tested for differences among Stations using Pearson's Chi-square test statistic. Successive sampling events on which abundances of these families generally exceeded 100 individuals per Station were selected for the analysis. Because no more than 20 individuals of a particular taxon were measured in each replicate, these lengths were "bootstrapped" to the total number of individuals present in the replicate, and lengths from all replicates from each station were used for the Chi-square test. Bin sizes for engraulids were in 2 mm increments from 2 to >38 mm, 1 mm increments from 1 to >8 mm for gobiids, and 1 mm increments from <19 to 42 mm for clupeids. In all cases, the null hypothesis was homogeneity of length-frequency among Stations. All pair-wise comparisons of Chi-square length frequencies were tested with Bonferroni-adjusted *p* values.

Abiotic data

An analysis of covariance (ANCOVA) was used to detect differences in abiotic data among the Stations. Sampling date (julian day) was used as the covariate in order to adjust each Station dependent variable mean for the temporal nature of sampling over the spring season. Except for the test involving salinity, the assumption of parallel slopes of the regression lines was accepted. Homogeneous subsets were delineated using Tukey's honestly significant difference (HSD) multiple comparison method, which tests for differences among all pair-wise comparisons of means while controlling the maximum experimentwise error rate ($\alpha = 0.05$). For the salinity ANCOVA, least squares estimated marginal means for each Station were compared using a Tukey-adjusted pair-wise comparison method. There was no significant covariate term in the test involving pH, therefore differences among Stations was compared with a one-way analysis of variance.

IV. RESULTS

Abiotic Data

Hydrological parameters were measured at each site during each sampling event. Descriptive values for abiotic variables [temperature (ºC); salinity (PSU); pH (SU); D.O. (mg l^{-1} and % saturation); turbidity (m)] are reported by Station in Table 1. Differences in abiotic variables between Stations were tested with a one-way ANCOVA and the results are presented in Table 2.

Water temperature showed a typical seasonal increase throughout the study period, although two strong cold fronts depressed temperatures across the study area in early March and again in mid-April. Temperature was not significantly among Stations, either in Nueces Bay, Nueces River, or the Delta region (Fig 3a). The influence of the CPL discharge on surface water temperatures was not seen during this study period, as opposed to previous years where the warm water associated with the CPL outfall was a prominent feature (Newstead 2002).

Salinity values followed a typical estuarine gradient pattern, with the lowest values recorded in the river (104A) and the highest values near the connection with Corpus Christi Bay (CPL and NB1). Mean salinity was significantly different between the river, the river discharge and delta locations, and the eastern margins of the bay (Table 4). The greatest ranges (15.1 to 19.1 PSU) of salinities occurred in the western margins of the back-bay (RB51, NB1, and 313), nearest to the river discharge location. Salinity generally increased throughout the study period, where the most notable increase took place at the delta station, where salinity values at RB51 were increasing more rapidly by the beginning of summer than at any other Station (Fig 3b).

In general, pH measurements were well within normal ranges for estuarine waters, with values relatively constant across the bay Stations (NB1, 313, CPL, and NC). The mid-April peak in pH at all the Station except for the 104A coincided with the elevated D.O. values associated with the lower temperatures caused by the cold-frontal passage (Fig 3c).

Dissolved oxygen levels peaked in mid-April, and declined estuary-wide towards the end of the spring recruitment period. This peak corresponded with the strong frontal passage, where the colder water temperatures allowed for increased amounts of oxygen to remain in solution (Fig 3d). When adjusted for temperature and salinity, mean D.O. percent saturation levels were at or above 100% level (Table 3).

Turbidity was highest in the river, delta, and river discharge locations, with the highest turbidity recorded at Station 104A (Fig 3e).

Table 1. Hydrological parameters of study stations in Nueces Bay, Texas during 2003 sampling events.

	Station	N	Mean	Std. Dev.	Min.	Max.
Temperature (ºC)	104A	8	22.5	5.3	13.7	29.9
	313	8	21.4	5.7	12.5	28.8
	CPL	8	22.0	5.8	12.5	29.8
	NB1	8	21.6	5.4	13.3	28.5
	NC	8	22.4	5.8	13.2	30.7
	RB51	8	22.1	5.3	13.7	28.2
Salinity (PSU)	104A	8	2.7	2.5	0.6	6.5
	313	8	14.0	6.2	6.9	23.7
	CPL	8	15.4	3.7	15.4	24.9
	NB1	8	14.7	5.5	9.2	24.3
	NC	8	23.6	3.3	19.7	27.8
	RB51	8	15.5	6.5	9.5	28.5
pH (SU)	104A	8	8.2	0.1	8.0	8.4
	313	8	8.1	0.6	8.0	8.2
	CPL	8	8.1	0.1	8.0	8.3
	NB1	8	8.1	0.1	8.0	8.3
	NC	8	8.1	0.1	8.0	8.2
	RB51	8	8.2	0.2	8.0	8.5
D.O. (mg $l^{-1)}$	104A	8	9.9	1.5	7.9	11.5
	313	8	8.3	1.7	6.0	10.6
	CPL	8	8.7	1.7	7.2	11.8
	NB1	8	8.5	1.7	6.2	11.3
	NC	8	8.4	1.4	7.1	11.2
	RB51	8	8.8	1.6	6.4	11.1
D.O. (% saturation)	104A	8	114.7	13.5	92.5	133.4
	313	8	99.4	7.7	89.3	109.8
	CPL	8	109.9	12.8	99.1	136.4
	NB1	8	102.8	7.8	92.3	116.6
	NC	8	109.3	10.8	95.8	132.7
	RB51	8	108.1	7.8	96.3	118.1
Secchi Depth (m)	104A	7	0.35	0.09	0.30	0.51
	313	8	0.54	0.20	0.24	0.86
	CPL	8	0.74	0.33	0.25	1.31
	NB1	8	0.41	0.22	0.10	0.78
	NC	8	0.66	0.33	0.19	1.23
	RB51	8	0.38	0.18	0.27	0.83

Table 2. Results of abiotic variables ANCOVA among stations in Nueces Bay, Texas, spring 2003. Station means are arranged from high to low values. Means joined by a line indicate a non-significant difference (Tukey's HSD test, *P* < 0.05).

Dependent Variable	df	F-Value	*P* > F	Homogeneous subset
Temperature	5,36	0.14	0.983	104A NC RB51 CPL NB1 313
pH	5,42	2.47	0.048	104A RB51 NB1 CPL NC 313
D.O. mg l^{-1}	5,36	1.89	0.120	104A RB51 CPL NB1 NC 313
D.O. % sat.	5,36	2.30	0.065	104A CPL NC RB51 NB1 313
Turbidity	5,36	3.91	0.001	CPL NC 313 NB1 RB51 104A

Table 3. Results of salinity ANCOVA among stations in Nueces Bay, Texas, spring 2003. Station least square estimated marginal means adjusted for the covariate (pdiff / adjust = Tukey, *P* < 0.05; SAS 2000). Comparisons in bold are significantly different.

		Pr > | *t* | for LS Mean(*i*) = LS Mean (*j*)				
Station	Mean Salinity	104A	313	CPL	NB1	NC
104A	2.7					
313	14.0	<***0.001***				
CPL	15.4	<***0.001***	***0.002***			
NB1	14.7	<***0.001***	0.997	***0.007***		
NC	23.6	<***0.001***	<***0.001***	0.105	<***0.001***	
RB51	15.5	<***0.001***	0.881	***0.036***	0.987	<***0.001***

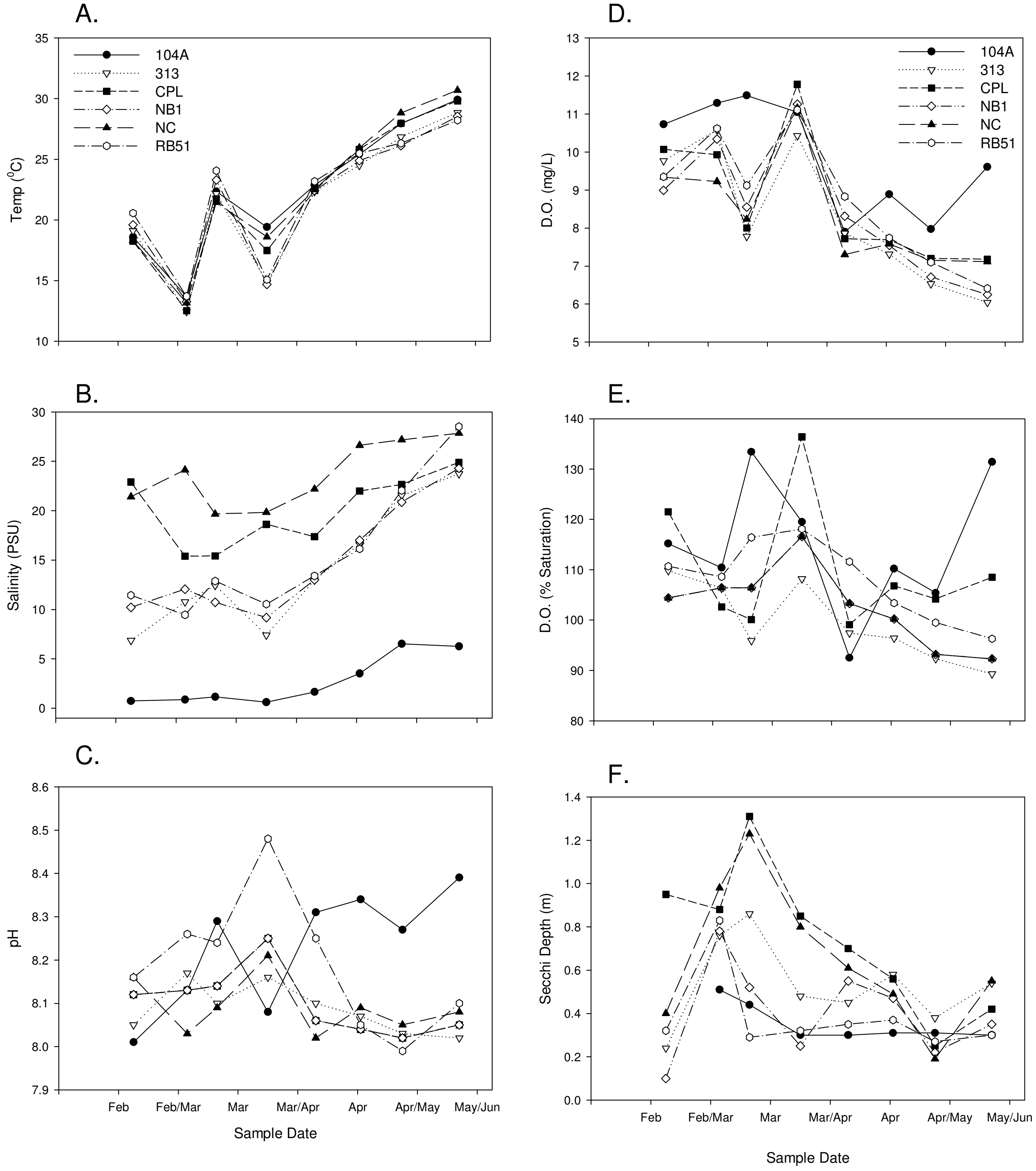

Figure 3. Abiotic parameters from Nueces Bay during spring 2003. A). Temperature; B). Salinity; C). pH; D). Dissolved Oxygen; E). Dissolved Oxygen Percent Saturation; and F). Turbidity. Station designation legend for each plot given in A. and D.

Ichthyoplankton Community

Eight sampling trips were conducted over the spring 2003 recruitment period, resulting in 142 samples. On two occasions, only two of the three replicate samples were collected at a Station. Both departures from the study protocol were at the upper bay/delta station (NB1 on 16 APR and 1 MAY). A total of 82,370 larval and juvenile fishes, representing at least 28 species from 18 families, were collected during this study. Additionally, a total of 562 postlarval penaeid shrimp were also collected. Numerically, three families accounted for 97.5% of the total number of individuals (Gobiidae 43.6%, Engraulidae 37.3%, and Clupeidae 16.6%). A complete taxonomic list with mean densities at each Station is given in Appendix 1. Graphical representations of larval densities across Stations over time are given for all fish combined (Fig. 3), Gobiidae (Fig. 4), Engraulidae (Fig. 5) and Clupeidae (Fig. 6). Overall spring ichthyoplankton abundance was bimodal in 2003, with the majority of recruitment taking place in May (Fig. 3). Gobies were abundant in late spring, with highest densities found throughout the bay in mid-May (Fig 4). Gobies were the only family to have a considerable proportion of their overall abundance found in the river. Larval (preflexion, flexion and postflexion) anchovies (*Anchoa* sp.) were found in highest densities in the eastern margins of the bay (Stations CPL and NC) during early to mid-may, while juvenile and larger anchovies (*A. mitchilli* and *A. hepsetus*) occurred mostly at the delta and back-bay Stations (RB51 and NB1; see Fig. 5). Clupeids, mostly Gulf menhaden (*Brevoortia patronus*), were also found primarily at these same Stations, although clupeids were found much earlier in the spring recruitment season (mid-February to April) than were the engraulids. *B. patronus* was also abundant in the river Station, although their densities at this Station were generally low compared to the bay (Fig 6). The late season increase of clupeids in the delta (RB51) was attributed to a different species, finescale menhaden (*B. gunteri*), which has a later spawning season than *B. patronus*.

Ordination

Springtime ichthyoplankton communities across the study transect in Nueces Bay revealed clear differences in both space and time with the MDS procedure. Similar to the environmental results seen in the salinity structure of the bay, the Stations were separated based on their community compositions into the delta, river and river discharge locations, and eastern margins of the bay (Fig. 7a). The delta (RB51) samples maintained a cohesive group in the upper right quadrant of the plot (arc outlined by the dotted line in Fig 7a), while Station in the eastern portions of the bay (CPL and NC) formed a similar, but opposite facing arc across the lower half of the MDS space. The river and river discharge locations were intermediate, occupying a diagonal across the plot. When viewed according to sample date (Fig. 7b), additional structure to these Station configurations is revealed. In the upper right hand quadrant, the cohesive nature of the RB51 samples shows that an “arc” is formed as a result of

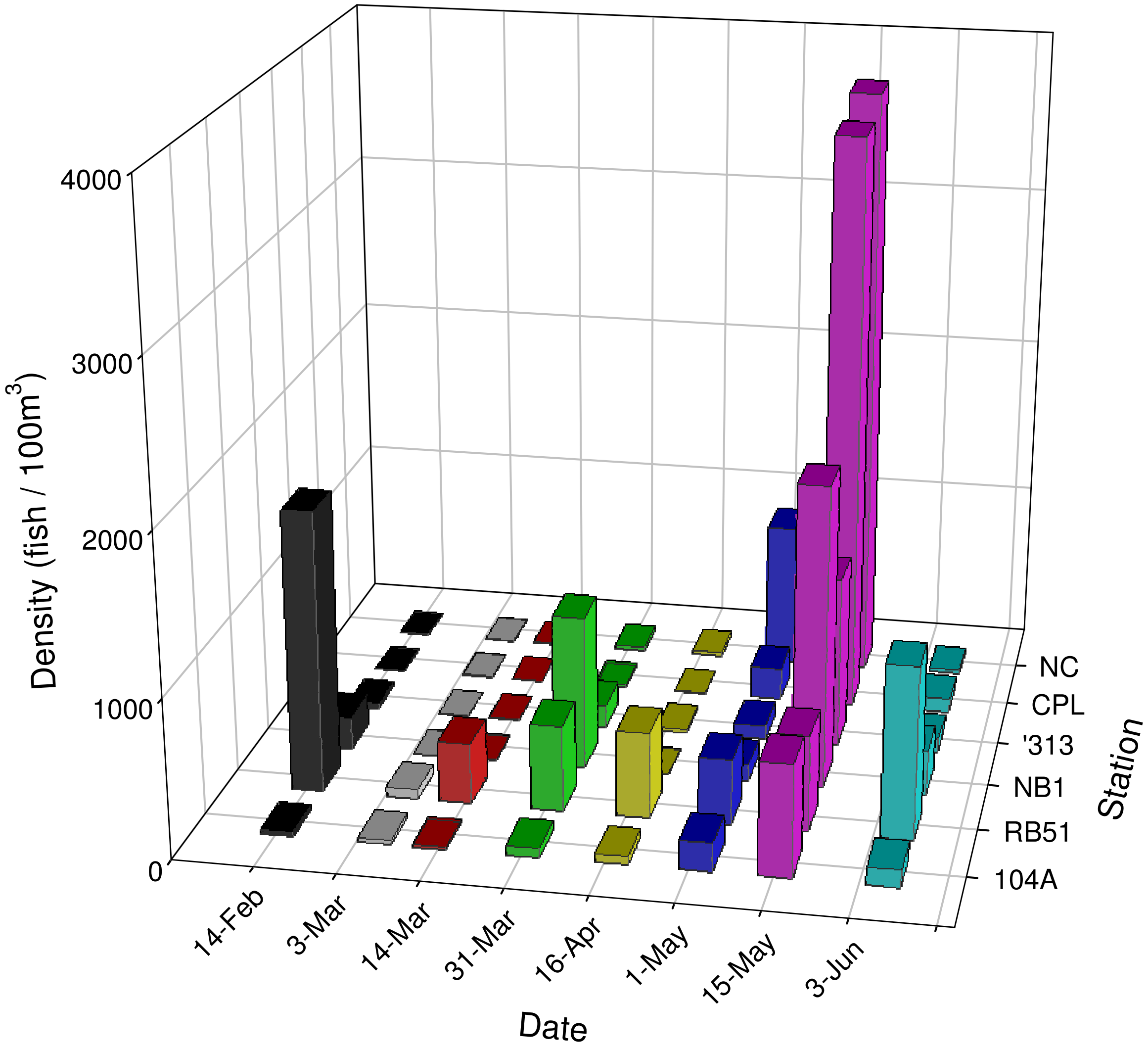

Figure 4. Total fish densities (fish 100 m^{-3}) by station for all sampling events in Nueces Bay during 2003.

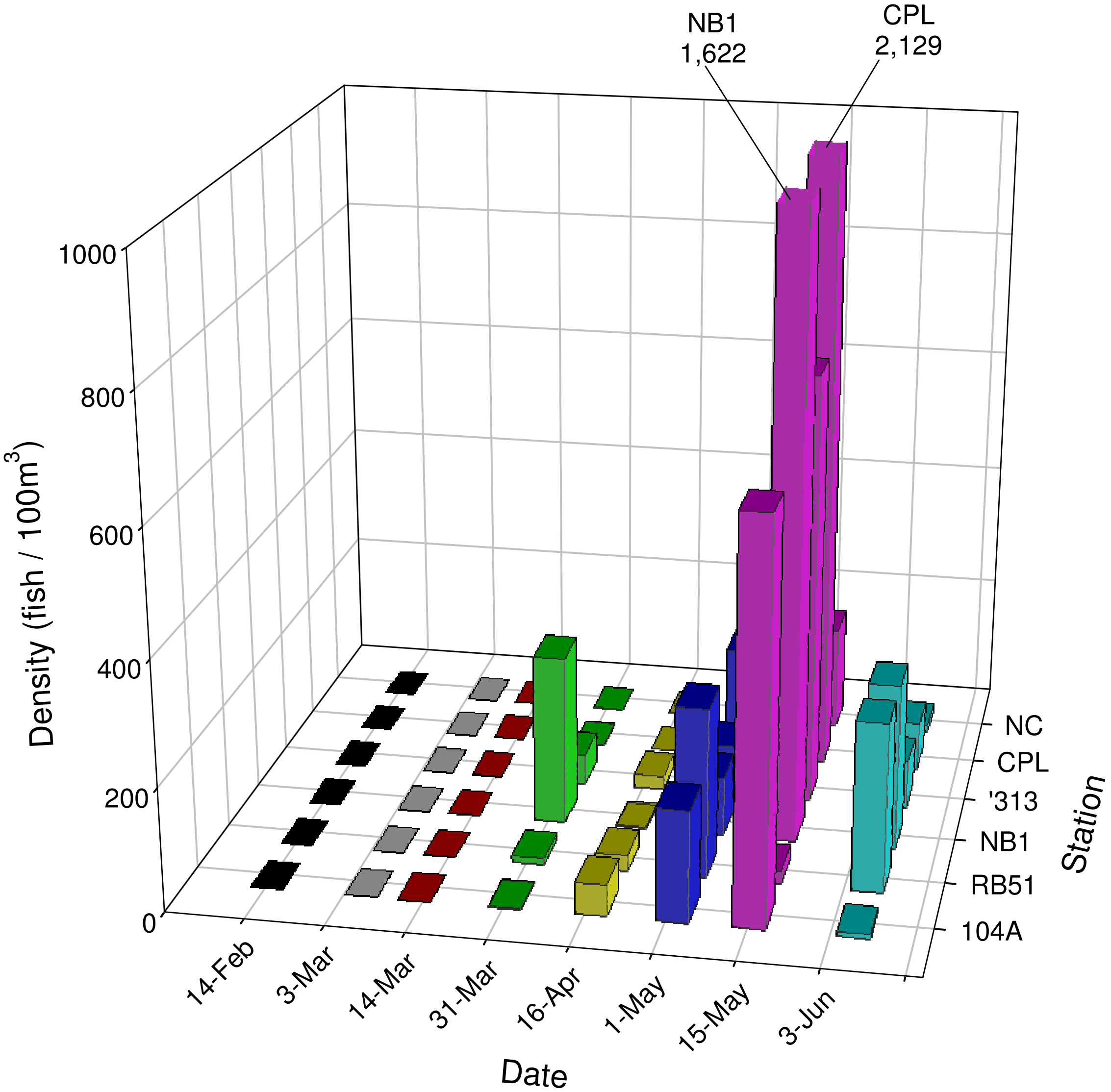

Figure 5. Total densities (fish 100 m^{-3}) of Gobiidae by station for all sampling events in Nueces Bay during 2003.

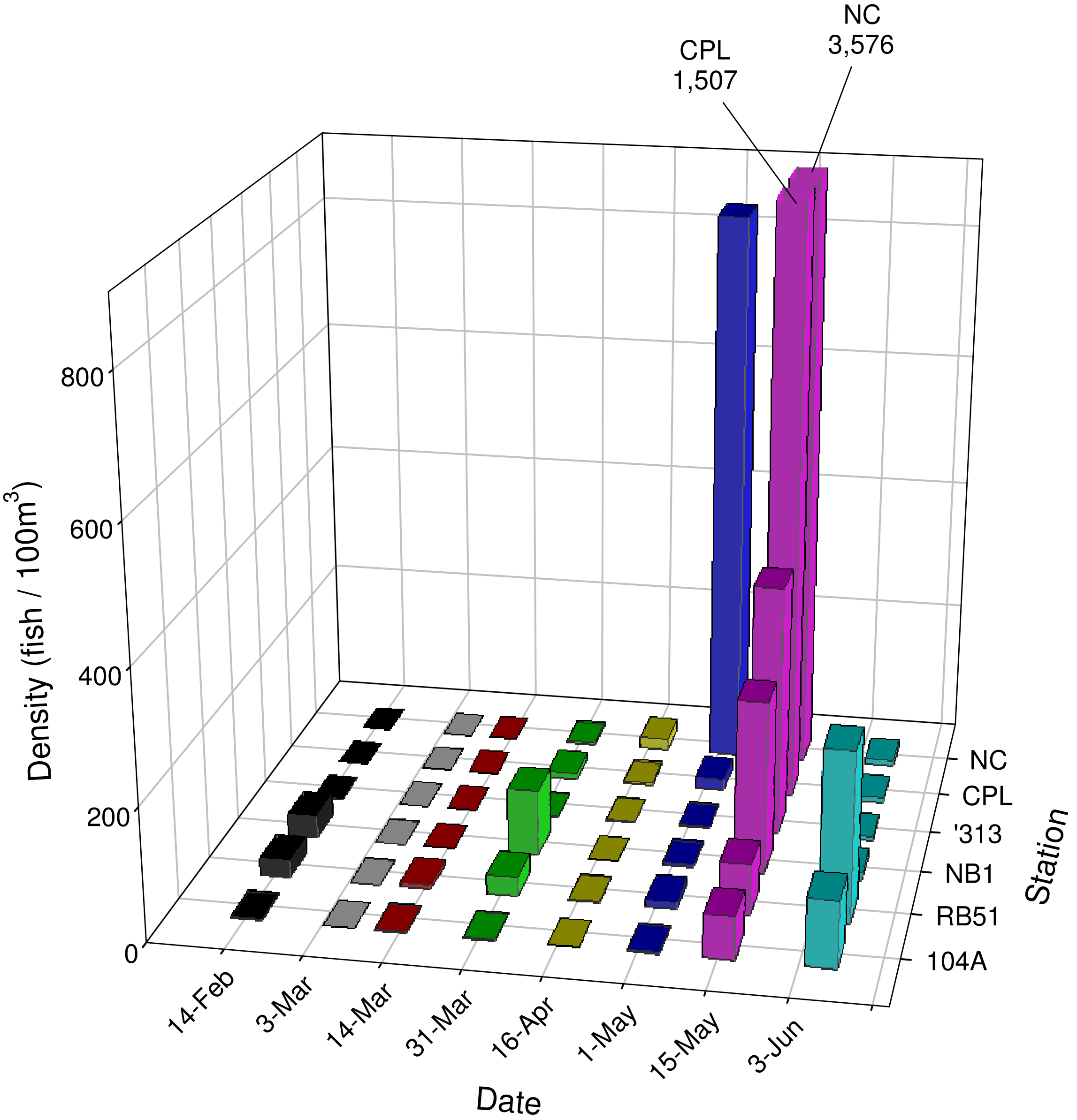

Figure 6. Total densities (fish 100 m^{-3}) of Engraulidae by station for all sampling events in Nueces Bay during 2003.

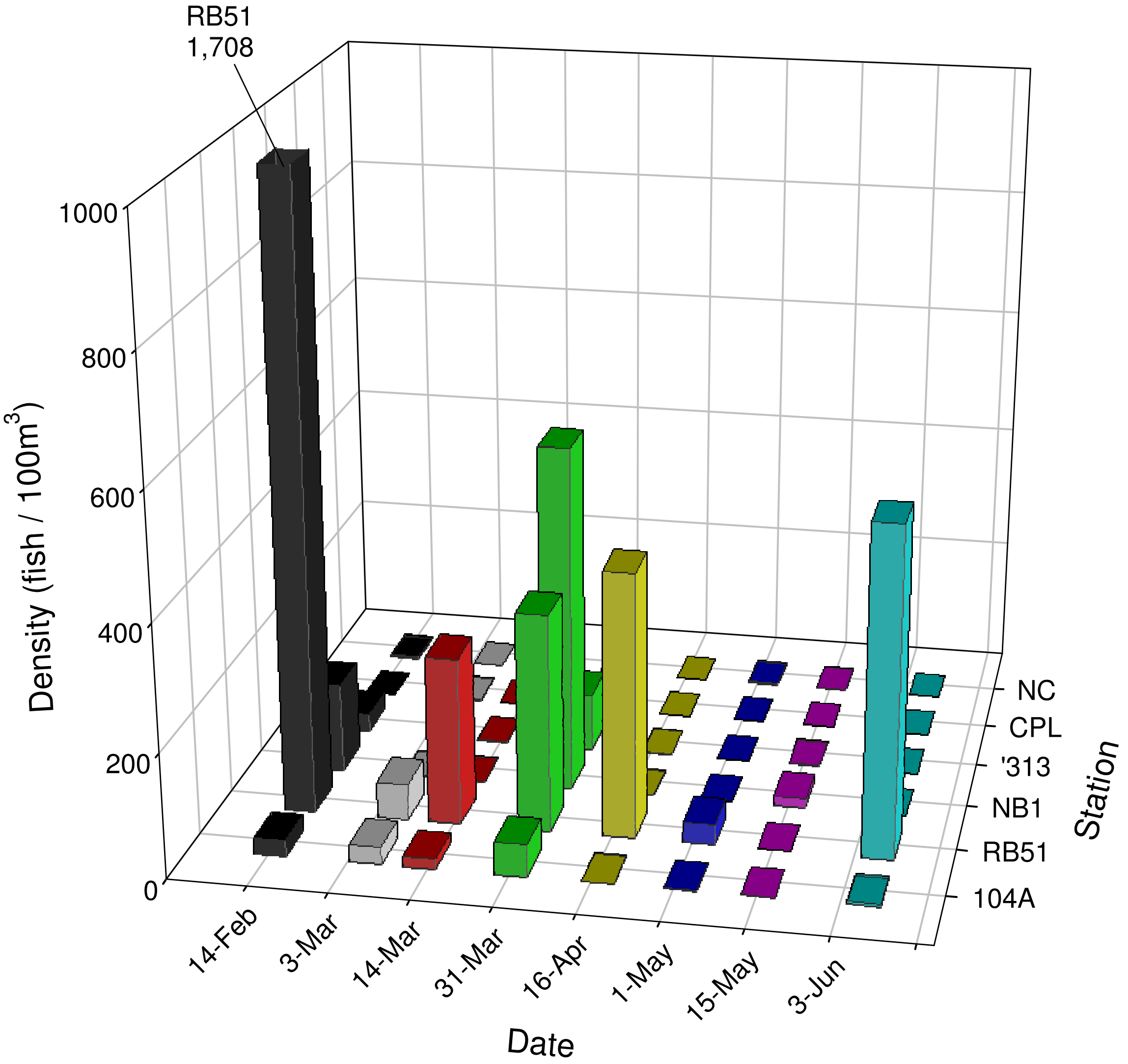

Figure 7. Total densities (fish 100 m^{-3}) of Clupeidae by station for all sampling events in Nueces Bay during 2003.

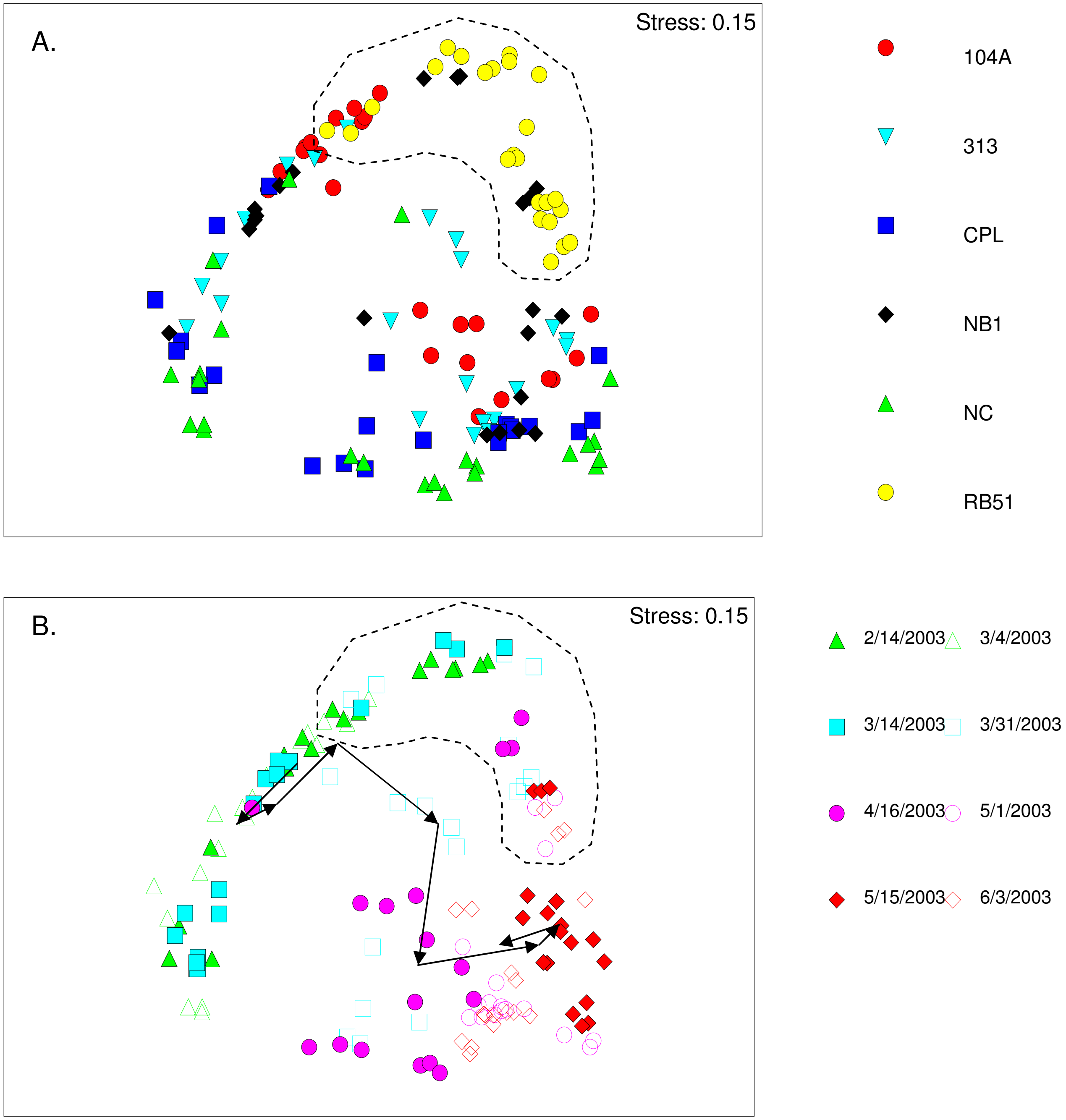

Figure 8. MDS configuration of spring 2003 ichthyoplankton sampling in Nueces Bay, Texas. A). Plotted using Stations as the symbols. B). Plotted using sample date as the symbols, with an arrow through the center of each sample date space indicating sample sequence through the spring season.

For comparison, all samples from RB51 are enclosed in each plot. The temporal sequence of samples, moving left to right across the height of the arc, is seen when comparing Figures 7a and 7b. A similar progression is seen in the lower “arc” defined by the CPL and NC samples (eastern side of the bay), with the sequence of samples moving left to right across the bottom of this arc. The river and river discharge Stations also showed a clear left to right seasonal progression across a diagonal of the MDS configuration. The main shift in the temporal progression of the communities across the study transect occurred at the end of March and the beginning of April, where the centers of the MDS configurations moved from the upper left to the lower right quadrants (Fig. 7b). In the early spring, all the Stations were spread along the upper left hand side of the MDS plot, shifting to the lower right hand side of the plot by the end of spring.

SIMPER analysis was used to determine the taxa most responsible for the configurations seen in the MDS plots. The plankton community in the river (104A) was dominated by larval gobiids and engraulids (*Anchoa* sp.), in addition to juvenile clupeids (*Brevoortia patronus*; see Table 4). Estuarine-dependent taxa, such as penaeids, mugilids (*Mugil cephalus*), and sparids (*Lagodon rhomboids*), were noted from this Station, although their abundance levels were generally low. At the river discharge Stations (313 and NB1), the abundance levels of larval gobiids and engraulids increased towards the back of the bay, into the delta region. *B. patronus* abundance increased dramatically at NB1, as did the larger, juvenile-sized anchovies (*Anchoa mitchilli*). Taxa found at high abundance levels in the river discharge/back-bay area included estuarine-dependent penaeids, sciaenids (*Micropogonias undulatus*), and the marine-resident *Elops saurus*. The highest abundance levels, by orders of magnitude in some cases, for all estuarine-dependent and many estuarine-resident taxa (e.g., antherinids, cyprinodontids, and the sciaenid *Leiostomus xanthurus*) were found at the delta Station (RB51; see Table 4). Juvenile size clupeids, engraulids, and penaeids, as well as larval size *Menidia* sp. and *L. xanthurus* were all found at greatly increased abundance levels in the delta. The eastern portions of the bay (CPL and NC) were dominated by larval size engraulids, and gobiids (Table 4). Estuarine-resident taxa found at higher abundance levels farthest away from the inflow location included *Gobiesox strumosus, Syngnathus scovelli, Bairdiella chrysoura*, and blenniids.

The spatial structure of these communities over time, combined with the results of the ANOSIM test, is shown in Fig. 8. Based on 1,999 permutations of the sample labels, the Global *R* value for the one-way test was 0.276 (p = <0.0001). Pair-wise comparison *R* values for each sampling Station are presented in Table 5. Three temporally consistent groups of Stations were found with the second stage MDS; the delta, the bay, and the river discharge area (Fig. 8). Station RB51 was significantly different from all other sampling Stations throughout the spring 2003 period. Within the bay, there was a great deal of overlap seen in the communities found at NB1, 313, CPL, and NC. Each Station was similar in community composition to every other bay Station (each is connected by 3 lines to all other bay Stations). The river discharge area (104A, 313, and NB1) were all similar in their communities during spring 2003, although the river Station (104A) was significantly different from the eastern portion of the bay (Fig. 8).

Table 4. SIMPER analysis mean densities (fish 100 m^{-3}), and average similarity (S*i*, within-group) of the spring 2003 ichthyoplankton communities at each Station. Early Life History (ELH) designation follows those presented in Patillo et. al (1997): ED – Estuarine Dependent, ER – Estuarine Resident, MR – Marine Resident.

		Station					
Taxa	ELH	104A	313	CPL	NB1	NC	RB51
Penaeidae	ED	0.21	-	0.86	3.45	1.16	13.85
Elopidae							
Elops saurus	ED	-	-	-	4.99	0.04	8.64
Clupeidae							
Brevoortia gunteri	ER	-	-	-	-	-	8.19
Brevoortia patronus	ED	15.60	14.30	0.38	91.10	1.19	452.69
Engraulidae							
Anchoa sp.	ER	17.54	41.36	187.24	30.70	557.49	11.96
Anchoa mitchilli	ER	3.61	7.20	0.88	22.40	-	42.84
Gobiesocidae							
Gobiesox strumosus	ER	-	0.24	0.36	-	2.35	-
Atherinidae							
Menidia sp.	ER	0.23	0.16	0.53	0.21	-	32.68
Cyprinidontidae							
Cyprinodon variegatus	ER	-	-	-	-	-	0.89
Fundulus grandis	ER	-	-	-	-	-	0.46

Table 4. (cont.)

		Station					
		104A	313	CPL	NB1	NC	RB51
Syngnathidae							
Syngnathus scovelli	ER	-	-	-	-	0.18	-
Mugilidae							
Mugil cephalus	ED	0.15	-	-	-	-	3.11
Sparidae							
Lagodon rhomboides	ED	0.05	0.08	0.60	0.11	0.76	2.07
Sciaenidae							
Bairdiella chrysoura	ED/ER	-	-	-	-	1.52	-
Leiostomus xanthurus	ED	-	-	0.04	-	0.07	10.39
Micropogonias undulatus	ED	-	-	-	1.29	-	-
Gobiidae	ER	109.66	117.06	281.59	297.18	27.95	78.51
Blenniidae	ER/MR	-	-	0.77	0.24	1.71	-
Tetraodontidae	MR	-	-	-	-	0.31	-
Average Similarity (S_i)		23.82	17.32	10.54	17.00	12.69	35.41

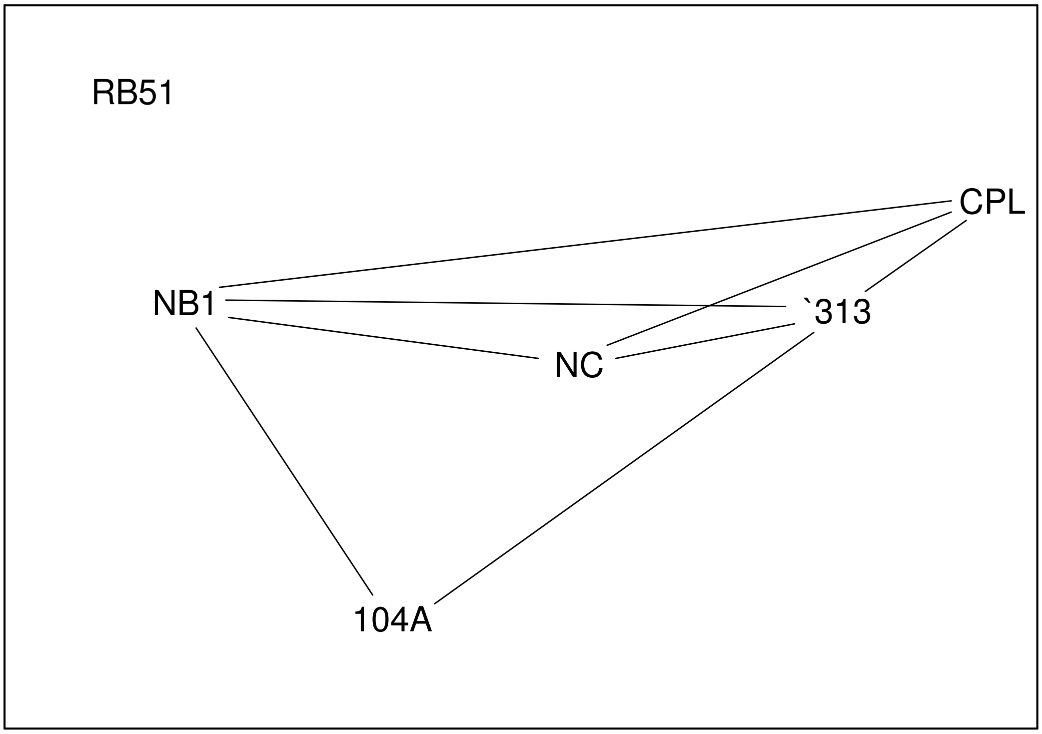

Figure 9. Station configuration (second stage MDS) produced by species similarities over each sample date-Station combination. Stress = 0.01. Stations connected by a line are not significantly different based on ANOSIM pair-wise comparisons (Bray-Curtis similarity measure of the entire community over the spring 2003 sampling season).

Table 5. Analysis of Similarity (ANOSIM) *R*-statistic values of the Stations pair-wise comparisons, based on 1,999 random permutations of the sample labels. Significant *R* values (*p* < 0.001) identified in bold.

Station	104A	313	CPL	NB1	NC
104A					
313	0.038				
CPL	***0.233***	0.100			
NB1	0.001	0.030	0.172		
NC	***0.285***	0.176	0.004	0.239	
RB51	***0.481***	***0.592***	***0.711***	***0.374***	***0.724***

Length-Frequency Distributions

The most abundant ichthyoplankton (Gobiidae, Engraulidae, and Clupeidae numerically represented 97.5% of the total) were tested for differences in length-frequencies among Stations. Additionally, post-larval shrimp (Penaeidae) were also tested for differences in their length-frequencies. Median size of gobiid larvae throughout Nueces Bay was 4.0 mm, with the greatest numbers of larvae collected in the back bay at NB1 (Table 6). Length-frequencies were unimodal at each Station (Fig. 10), although a number of pair-wise comparisons were identified as significantly different (Table 5). The largest individuals were found in the back-bay and river Stations (RB51, NB1, and 104A). While the fewest numbers of gobiids were collected near the mouth of the Bay (NC), closest to the connection with Corpus Christi Bay, large numbers were collected from the nearby CPL location.

The overall median size for engraulids was 11.6 mm, although this was due to very large numbers of larval *Anchoa* sp. at CPL and NC (Fig. 11). Engraulids were generally discernible to the species level by approximately 15-18 mm SL, and the majority of the juvenile engraulids were *Anchoa mitchilli*. In the back-bay Stations, multiple cohorts of engraulids were encountered, with greatest proportions of the larger, juvenile-sized individuals (>22 mm SL) encountered at the front of Delta (NB1; see Table 6). Based on the Chi-square test, only the eastern part of the bay (CPL and NC) had similar length-frequencies of engraulid larvae and juveniles (Table 7), with the bulk of the smallest individuals (< 8 mm SL) found nearest the connection to Corpus Christi Bay (Fig. 11).

For comparisons involving clupeids only *B. patronus* was used, as *B. gunteri* was only found at the delta Station and the other clupeoid species encountered (*Dorosoma* spp. and *Harengula jaguana*) were not collected in appreciable numbers. Clupeids were collected at all Stations at a much larger size, with an overall median size of 22.2 mm SL. This family was found predominantly at back-bay and Delta Stations (NB1 and RB51), with high numbers also encountered in the river and river-discharge Stations (Table 6). The highest numbers of small individuals (<19 mm SL) were collected at in the eastern margin of the bay (NC, see Fig. 12), and their length-frequencies at this Station was significantly different from all other Stations except for the nearby CPL location (Table 7).

Based on their season of occurrence, the post-larval penaeid shrimps collected in this study were most likely brown shrimp, *Penaeus aztecus* (Patillo et. al, 1997). Relative to the numbers of finfish encountered in the spring, penaeids were collected in the plankton at far lower numbers (Table 6). Similar to other estuarine-dependent taxa, the greatest numbers of penaeids were found within the Delta (Table 4). Although present in the lowest numbers, the smallest individuals were encountered in the river and river discharge Stations (104A and 313). While the largest proportion of juvenile-size shrimp (>15 mm) were found within the Delta, little overall pattern of shrimp length-frequencies among Stations was evident with the Chi-squared tests (Table 7).

Table 6. Total numbers and median (mm) length by Station for length-frequencies of the most abundant ichthyoplankton families and taxa of particular interest (Penaeidae) collected in spring 2003, Nueces Bay, Texas.

	Gobiidae		Engraulidae		Clupeidae		Penaeidae	
Station	Median	*N*	Median	*N*	Median	*N*	Median	*N*
104A	4.8	4,853	12.1	1,037	21.8	607	9.6	9
313	4.0	5,742	11.7	2,580	22.1	624	11.4	5
CPL	3.5	10,765	6.1	6,795	22.2	19	12.9	34
NB1	4.1	11,332	18.3	1,895	21.9	2,225	12.3	54
NC	3.4	836	6.2	16,948	21.4	63	11.2	63
RB51	4.4	2,341	17.8	1,447	23.0	9,860	13.8	397

V. DISCUSSION

Estuarine-dependent fishery species require estuaries as nursery habitats for at least some portion of their life history stages (Weinstein and Brooks 1983; Worthington et al. 1992), and many of these species spawn far offshore and face numerous problems locating and entering estuarine nursery areas (Blaber and Blaber 1980; Valesini et al. 1997). Several environmental factors (e.g., prevailing winds, astronomical tides, local rainfall, and circulation patterns) can directly affect the distribution of the young organisms, and many of these abiotic factors may be affected by or work synergistically with freshwater inflows (Longley 1994). Physiological and behavioral mechanisms related to salinity and (indirectly) to freshwater inflow have been reported to affect the transport of these life stages within an estuary (Darnell and McEachran 1989; Wilber and Bass 1998; Tsou and Matheson 2002).

Salinity in Nueces Bay is highly and immediately affected by freshwater inflow, especially the large inflow events typical of the Nueces River. These large events, or freshets, quickly drop salinity levels to 10 PSU or less, with salinities recovering by approximately 10 PSU in the month following the freshet event (Bureau of Reclamation 2000). A continuation of this recovery (to a final salinity of 25-30 PSU in the following months, assuming no additional large inflows) is typically completed within 2-3 months (Freund and Dodson 1995). Newstead (2003) showed that large inflow events taking place during the spring recruitment period, either during the spring or preceding it by 2-3 months, produces a temporary decline in ichthyoplankton abundance in the early spring and delayes the majority of recruitment until later in the season. In 2003, the spring recruitment period was preceded by a number of very large

Table 7. Results of Pearson's Chi-square tests to detect length-frequency differences among Stations for families of interest collected during spring 2003, Nueces Bay, Texas. Significant differences among Stations (based on Bonferroni-adjusted *p* values) are identified in bold.

A.	Gobiidae Station						Engraulidae Station					
	104A	313	CPL	NB1	NC	RB51	104A	313	CPL	NB1	NC	RB51
104A	.						.					
313	***0.001***	.					***0.001***	.				
CPL	***0.001***	0.102	.				***0.001***	***0.001***	.			
NB1	0.154	***0.001***	***0.001***	.			***0.001***	***0.001***	***0.001***	.		
NC	***0.001***	0.028	0.340	***0.001***	.		***0.001***	***0.001***	0.054	***0.001***	.	
RB51	0.081	***0.001***	***0.001***	0.605	***0.001***	.	***0.001***	***0.001***	***0.001***	***0.001***	***0.001***	.

B.	Clupeidae Station						Penaeidae Station					
	104A	313	CPL	NB1	NC	RB51	104A	313	CPL	NB1	NC	RB51
104A	.						.					
313	0.011	.					0.286	.				
CPL	0.545	0.927	.				0.038	0.157	.			
NB1	0.021	0.803	0.934	.			***0.001***	0.212	0.067	.		
NC	***0.008***	***0.002***	0.037	***0.001***	.		***0.002***	0.215	***0.001***	***0.001***	.	
RB51	***0.001***	***0.001***	0.167	***0.001***	***0.001***	.	***0.001***	0.770	***0.001***	0.019	***0.001***	.

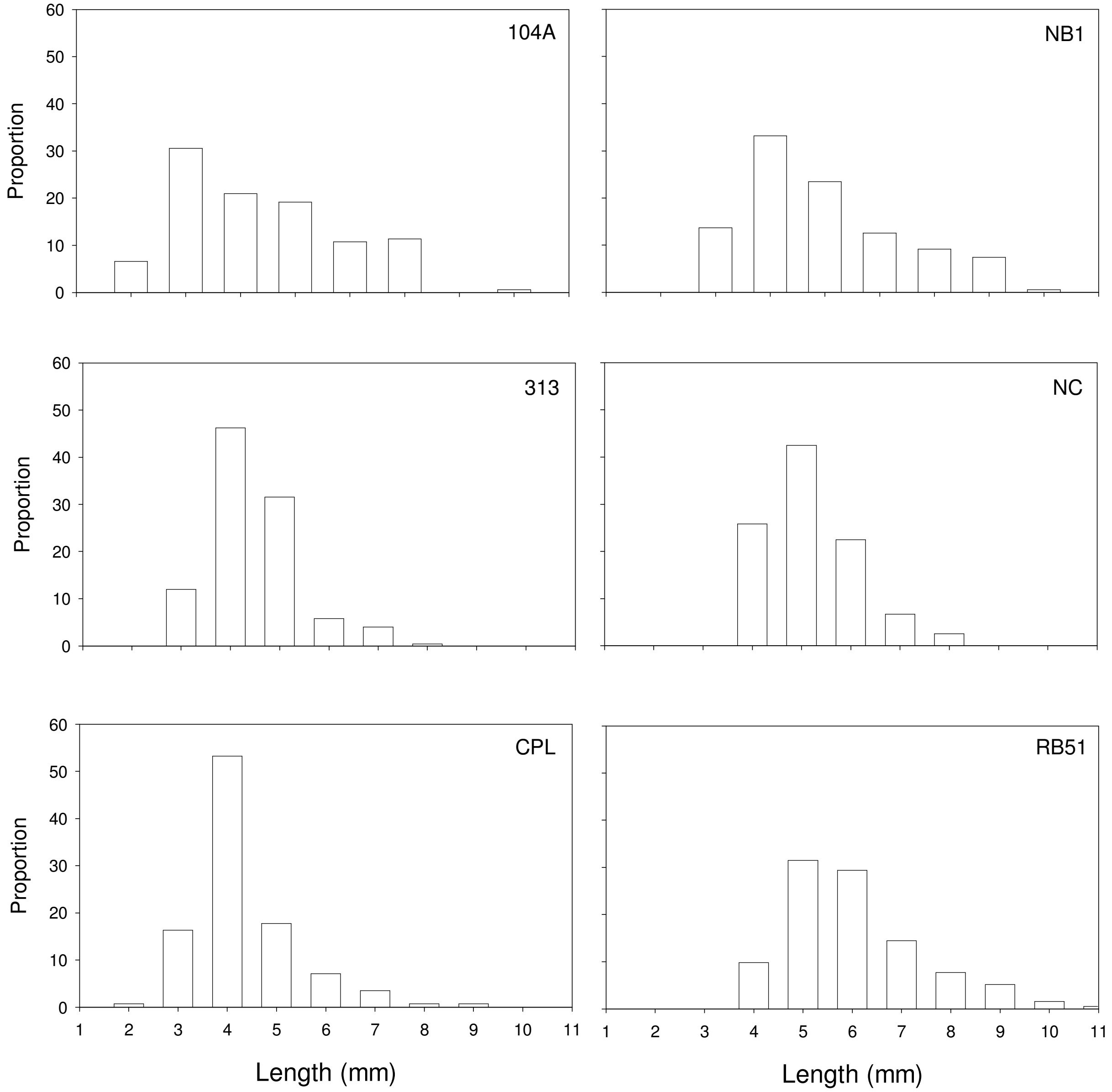

Figure 10. Length frequencies, arranged by Station, of gobiid larvae collected in Nueces Bay during spring 2003. All individuals >11 mm are included within the final bin.

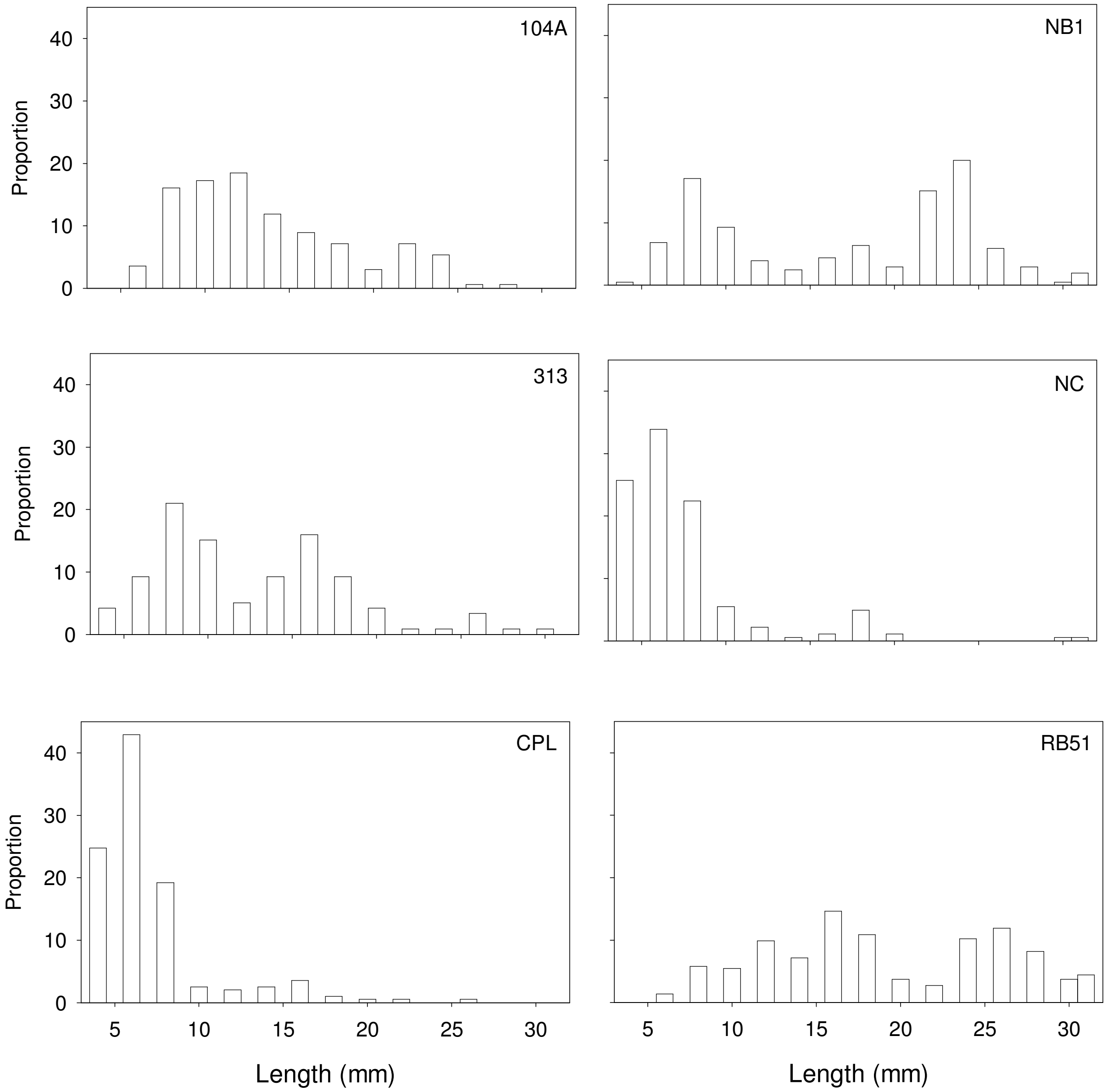

Figure 11. Length frequencies, arranged by Station, of engraulid larvae and juveniles collected in Nueces Bay during spring 2003. All individuals >30 mm are included within the final bin.

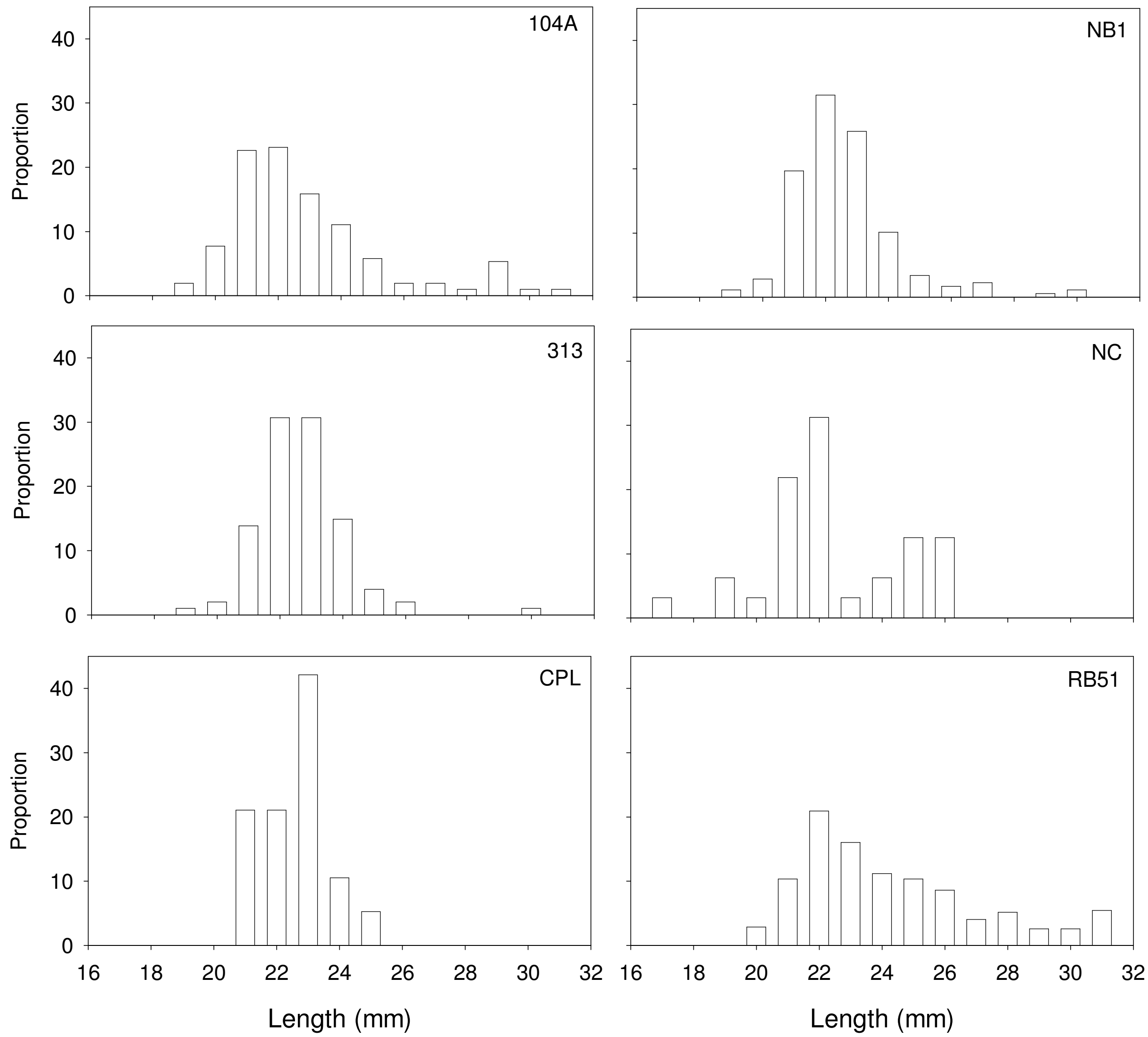

Figure 12. Length frequencies, arranged by Station, of *Brevoortia patronus* juveniles collected in Nueces Bay during spring 2003. All individuals <17 mm are included within the first bin.

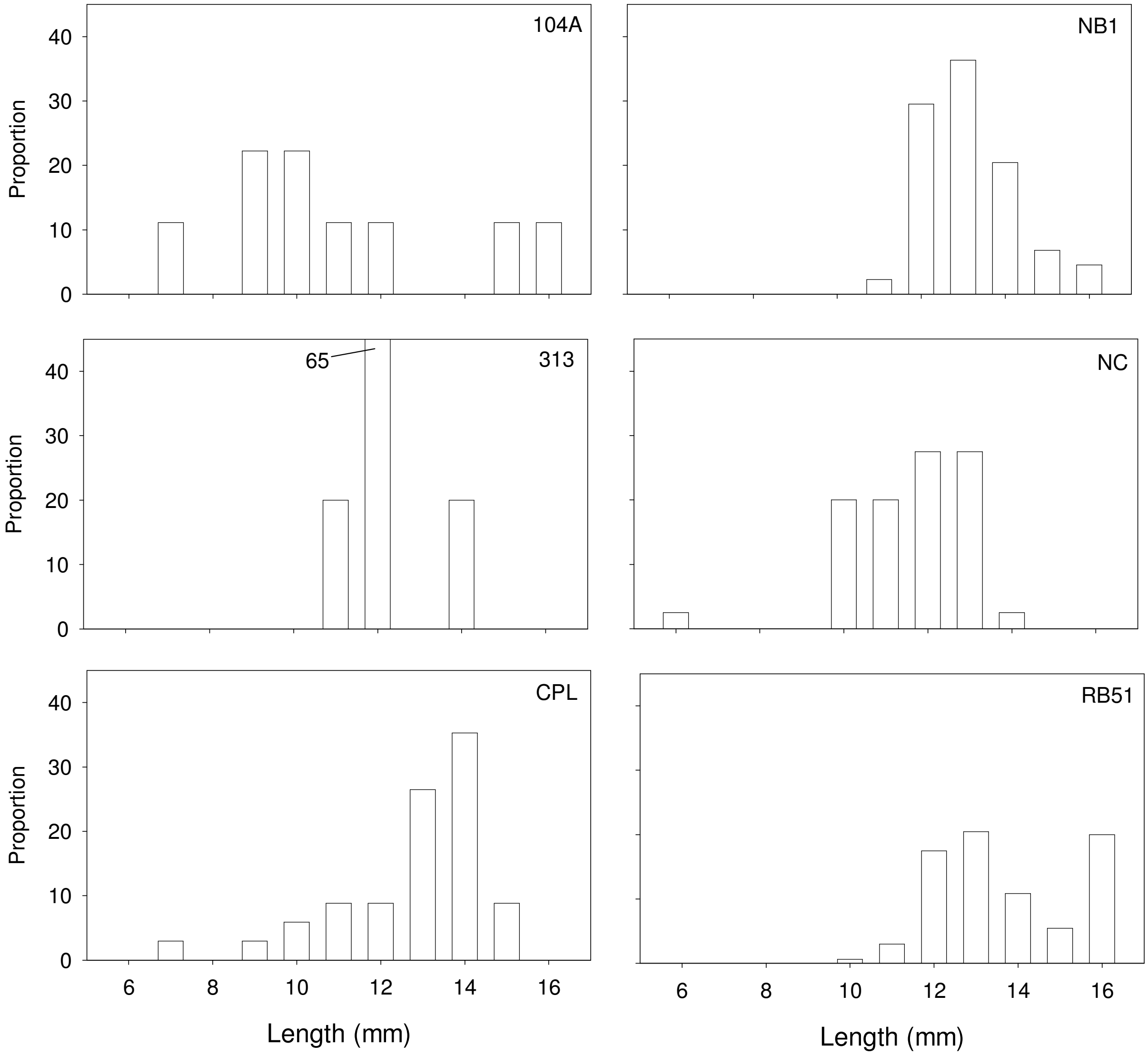

Figure 13. Length frequencies, arranged by Station, of penaeid post-larvae and juveniles collected in Nueces Bay during spring 2003. All individuals >16 mm are included within the final bin.

inflow events (Fig 14) and the rapid salinity recovery seen in the river discharge/back-bay Stations at the end of spring appears to confirm salinity patterns identified for this bay system (Fig 3b, March to June time period). As was the case seen in previous years (Tolan and Newstead 2003), the majority of recruitment was delayed until later in the season (Fig. 4). Average salinity across the Bay system was far lower than previously seen (Fig 15), and this could have allowed species that prefer lower salinity environments to flourish. Numerically, gobiids outnumbering the other dominant families for the first time in Nueces Bay (Engraulidae and Clupeidae; see Newstead 2003) and while their small size precluded positive identification to the species level, the preference of the naked goby (*Gobiosoma bosc*) for lower salinity estuarine and oyster reef areas (Hoese and Moore 1992) could provide evidence of the improved habitat characteristics of the Bay as a result of the abundance of freshwater inflow. The naked goby is the most abundant gobiid collected in the Nueces Bay system (Barbara Dorf, Ecosystem Leader, TPWD, personal communication). Gobiids were also the only taxa to have a substantial percentage of their total abundance collected in the river.

Other taxa encountered in the back-bay and delta region that could have benefited from the lower salinities included *Elops saurus*, *Micropogonias undulatus*, *Mugil cephalus*; and *Menidia* sp. Ladyfish (*E. saurus*) spawn year-round offshore (with a possible peak in the fall; Jones et al. 1978) and this species was found in highest abundance in the Delta. While most of the *E. saurus* specimens captured in this study were Stage I leptocephali (elongate, ribbon-like, transparent to semi-translucent larvae with a long fin-fold and forked tail) they appear to be actively seeking out the back-bay and Delta stations farthest from their source. Both Atlantic croaker (*M. undulates*) and striped mullet (*M. cephalus*) larvae are also known to actively seek out brackish water conditions (Hoese and Moore 1992), and like *E. saurus*, they too are spawned offshore and appear to be actively seeking out the delta region as their nursery habitat. Silversides (family Antherinidae), an estuarine-resident taxa that prefers shallow water, bay-margin regions (Hoese and Moore 1992) was collected in far higher numbers (by orders of magnitude) in the Delta than from any other Station in Nueces Bay.

Other than salinity and turbidity, no other abiotic variable showed any significant differences among the Stations throughout Nueces Bay in 2003. Average water temperature at the beginning of spring sampling period were comparable to previous years (18-20 ^{o}C; see Newstead 2003), with the two strong cold fronts in March depressing temperatures uniformly across the Bay. The absence of any heated water discharge from the AEP-CPL power plant near the CPL Station also reinforces the uniformity of temperatures seen across the entire estuary system. Dissolved oxygen concentrations ranged from 6.0 – 11.8 mg l^{-1} at all Stations and these values indicate no potential problems associated with depressed D.O. levels during the spring recruitment period.

The community-level analysis of similarity (ANOSIM) and multidimensional scaling showed that over the spring recruitment period, the delta Station (RB51) was biologically distinct from every other sampling location (see Fig. 9 and Table 5).

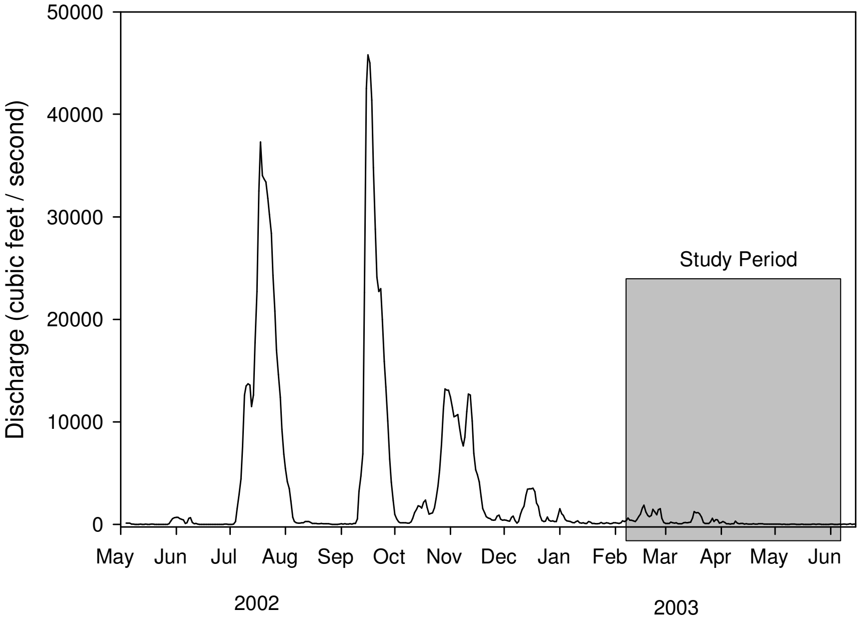

Figure 14. Surface inflow, measured as daily discharge at the Calallen gauge (USGS 08211500), preceding the spring 2003 ichthyoplankton recruitment study.

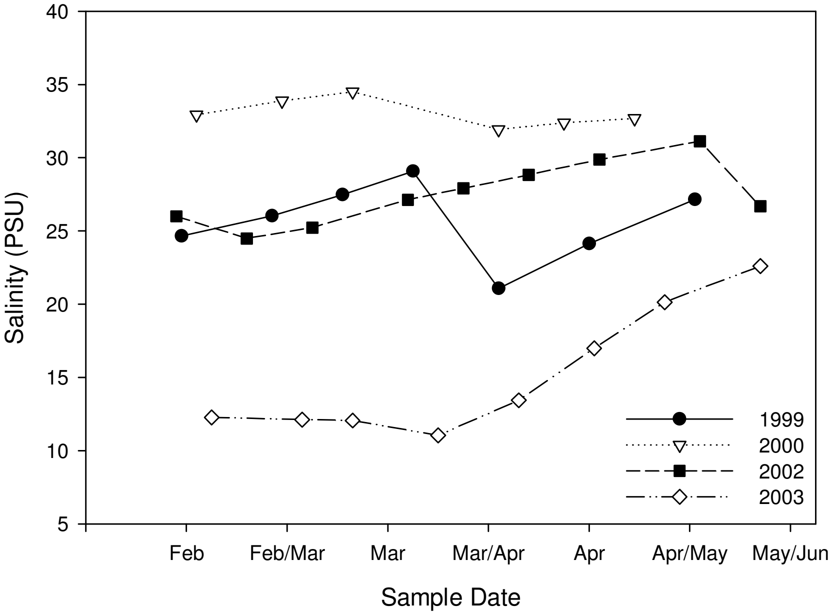

Figure 15. Average bay-wide salinity during the spring recruitment period (1999-2003).

Consistent groups of Stations were seen throughout spring 2003, with the river and river discharge locations (104A, 313 and NB1) making up one group, and the bay locations constituting another (NB1, 313, CPL, and NC). The eastern (NC and CPL) and western (313 and NB1) portions of the bay were very similar in their community compositions, and their spatial configurations in the second-stage MDS plot showed that while environmental gradients were generally lacking throughout the spring, biological community-based patterns could be seen. The MDS plot in Fig. 9 has been rotated such that the western-most Stations (RB51 and 104A) are on the left-hand side of the plot, and when viewed in this context, a source-to-nursery ground (right-to-left) gradation roughly matches the physical locations of the each of the Stations seen in Fig. 2. The community compositions are clearly different moving from the larval source to the nursery habitats (right to left in Fig. 9), with the greatest degree of species diversity found in the delta (see Table 4). Additionally, the length frequencies of each taxa under investigation showed that the largest individuals (i.e., those with the most advanced morphological and physiological development) were found within the delta or the back-bay Stations (RB51 or NB1; see Figures 10-13). Whether this increase in larger-sized individuals is in response to increased food availability associated with the high turbidity zone of the back bay areas or the river discharge zone is acting as a recruitment barrier by allowing only the most competent larvae to pass (Tolan and Newstead 2003), the back-bay and delta areas appear to be the preferred nursery habitat portions of Nueces Bay.

The summer and fall inflow events of 2002 were among the largest inflows ever recorded into Nueces Bay, and each was sufficiently large enough to cause overbanking of the main river channel and very large quantities of freshwater were carried directly into the delta. Bypassing the existing river discharge location (currently located approximately 2.6 km from the nursery habitats of the delta) and putting a portion of the freshwater inflows directly into upper Rincon Bayou for the expressed purpose of maximizing the benefits of freshwater inflow was one of the primary goals of the Nueces Delta Monitoring Plan (NEAC 2002). Based on the results of this study, coupled with the conclusions presented by Tolan and Newstead (2003) and Newstead (2003), the back-bay and delta regions of Nueces Bay appear to be the preferentially utilized by many fisheries species, especially the estuarine-dependent taxa.

VI. CONCLUSIONS

Larval abundance of many of the species occurring in the study (particularly those that spawn outside the bay and in the Gulf) appears to be positively affected by freshwater inflow. Though a strong salinity gradient is not always present in the bay, fish appear to be selectively recruiting to the more productive areas of the bay associated with the delta. It is postulated that pulsed freshwater inflow events that provide flushing of the highly productive delta marsh area may be more important for larval fish recruitment than lower flows that bypass the delta.

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APPENDIX

Taxonomic list of species collected (mean densities (fish 100m^{-3}) by Station) during spring season, 2002, ichthyoplankton sampling in Nueces Bay, Texas.

Taxa	STATION			
	1	2	3	4
O. Clupeiformes				
F. Clupeidae				
Dorosoma sp.	0	0	0	0.13
Brevoortia patronus	65.86	44.78	55.25	23.75
F. Engraulidae				
Anchoa hepsetus	0.15	0	0	3.5
Anchoa mitchilli	27.48	26.85	4.32	10.35
Anchoa sp.	4.59	18.4	28.4	1049.69
O. Aulopiformes				
F. Synodontidae				
Synodus foetens	0	0	0	0.03
O. Gobiesociformes				
F. Gobiesocidae				
Gobiesox strumosus	0.28	0.52	0.13	0.49
O. Atheriniformes				
F. Atherinidae				
Menidia sp.	0.09	0.53	0.02	0.03
O. Gasterosteiformes				
F. Syngnathidae				
Hippocampus zosterae	0	0	0.03	0.06
Syngnathus scovelli	1.22	1.73	0.11	0.33
O. Beloniformes				
F. Belonidae				
Strongylura marina	0.04	0	0	0.03
O. Perciformes				
F. Carangidae				
Oligoplites saurus	0	0	0	0.02
F. Sparidae				
Lagodon rhomboides	0.9	0.62	0.33	0.86
F. Sciaenidae				
Micropogonias undulatus	0.2	0.05	0	0
Cynoscion nebulosus	0	0	0	0.95

Appendix (cont.)

F. Sciaenidae				
Leiostomus xanthurus	0.1	0.25	0	0
Bairdiella chrysoura	0	0.1	0	7
F. Blenniidae	0.33	1.77	0.44	0.63
F. Eleotridae				
Dormitator maculatus	0	0.04	0	0
F. Gobiidae	202.25	225.75	45.62	16.3
Gobiosoma bosc	0.04	0	0	0
Microgobius sp.	0.1	0	0	3.47
Gobionellus oceanicus	0	0.04	0	0
Gobionellus boleosoma	0.4	0.02	0	0.08
O. Tetraodontiformes				
F. Tetraodontidae	0	0.06	0.18	0
Sphoeroides parvus	0	0	0	0
F. Diodontidae	0	0	0	0.29
UNIDENTIFIED FISH	0.04	0	0	0
TOTAL	304.22	321.57	134.86	1117.99